

# FLEX

Facility for Low Energy eXperiments in Buildings

## A NEW NATIONAL RESOURCE FOR ENERGY-EFFICIENT BUILDING TECHNOLOGIES



**A unique opportunity to collaborate with world-class research staff in development, simulation, and validation of efficient building technologies.**

FLEX will consist of building system test facilities to be located in new and existing structures at the Berkeley Lab.

Conduct focused research or product development on single components or whole-building systems integration.

Replace any building system such as exterior building envelope, windows and shading systems, lights, HVAC, energy control systems, roofs and skylights, or interior components such as furniture, partitions, and raised floors.



Construction of FLEX has commenced and will be *completed in 2013*. Berkeley Lab is seeking industry partners for the first experiments after launch.

# Technical Capabilities

- **Four newly constructed testbeds**
  - Two cells per testbed, 600sf each
  - One rotating testbed
  - One double-height 'big box' testbed
  - 7000SF total new testbed construction
- **Virtual design and visualization testbed**
- **Control hardware testbed**
- **Occupied plug-load and lighting testbed**

## Interchangeable Envelope Elements

- South facing and portion of north façade including glazing and opaque assemblies
- Exterior/Interior shading devices
- Reconfigurable roof insulation levels

## Commercial Interiors

- Variable ceiling heights to 11'6" above finished floor
- Potential for raised access floor to 2-ft height
- Partitioning for core/perimeter zoning, up to 3 zones per cell
- Two cells may be combined for larger floor-plan layouts

## HVAC

- One air handler per cell
- Dedicated central plant for every testbed, chilled and hot water
- Reconfigurable zonal systems (VAV, fan coil, radiant panels, chilled beam, displacement, under floor)
- Thermally isolated radiant topping slab with rigid insulation
- Up to three radiant in-slab zones per cell

## Rotating Testbed

- Configurable ceiling, HVAC, lighting, facades, access floor
- Resets position every 60 seconds to align with solar orientation for dynamic tests
- Enables testing at other orientations, e.g. west facing

## High Bay Testbed

- Reconfigurable skylights and clerestories
- 25-foot floor to ceiling height
- 25ft x 25ft floor-plate for equidistant daylight measurement
- Accommodates interstitial floor for 2-story applications
- Double height replaceable southern facade

## Data Acquisition (DAQ) & Controls System

- Local DAQ server per cell
- Ethernet and power raceways for cell sensors & instrumentation
- Telecomm services local to each cell
- Secure database per cell
- LabView based controls with customizable scripting tool
  - Base HVAC controls
  - Control sequences for other systems (lights, shades, etc.)
- Full monitoring and data visualization capabilities
- Interface capabilities for simulation and controls platforms



## Instrumentation (Partial)

- Power metering
  - HVAC, lighting, MELS at circuit and device level
  - Whole building, and end use level metering
- Thermal load measurement
  - Chilled and hot water Mag flow meters with temp sensor at each cell
- Other instrumentation
  - Occupancy sensors
  - Air supply flow measurements
  - Room pressure
  - Lighting & glare measurements
  - Envelope components, thermal measurements
  - Calibration capabilities

## Initial Fit Out Of Testbeds

- Each testbed's replaceable components will initially match performance characteristics of different eras
  - 1980S ashrae (two cells)
  - 90.1-2010 (three cells)
  - Title 24 2013 (three cells)
  - Net-zero design (one cell)

## Occupied Lighting & Plug Load Testbed

- Interior tenant improvement to Building 90
- Two zones for comparative studies
- All lighting individually circuited, metered and programmable
- Easily replaceable fixtures (plug-in)
- Occupancy sensors: computer, cube and lighting zone
- Outlets individually circuited and controllable
- Task / ambient lighting systems

## Virtual Design Testbed

- Two rooms
- Four SmartBoards per room
- Teleconferencing and large-scale visualization capabilities
- BIM through BEM platform interoperability testing

## Controls Hardware Lab

- Lab bench environment with soldering station
- Robust networking infrastructure access
- Controls mockup, testing and measurement equipment

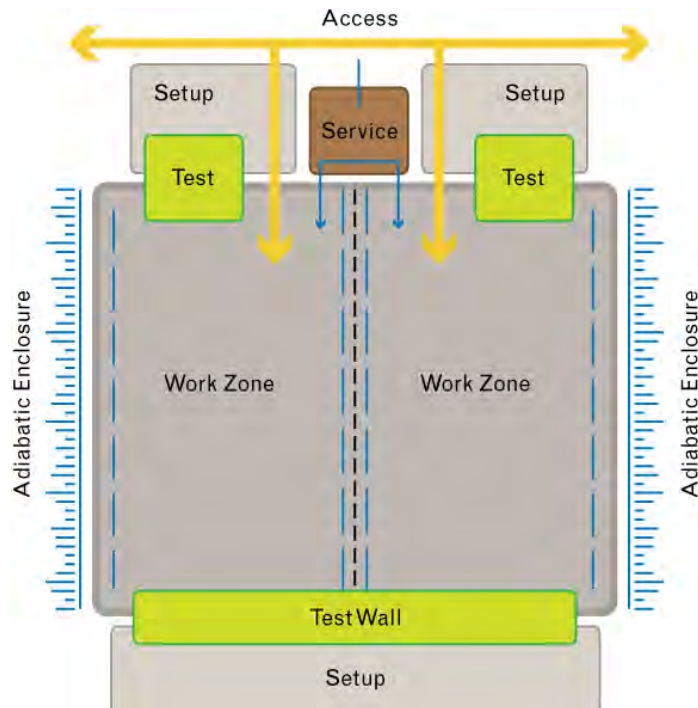
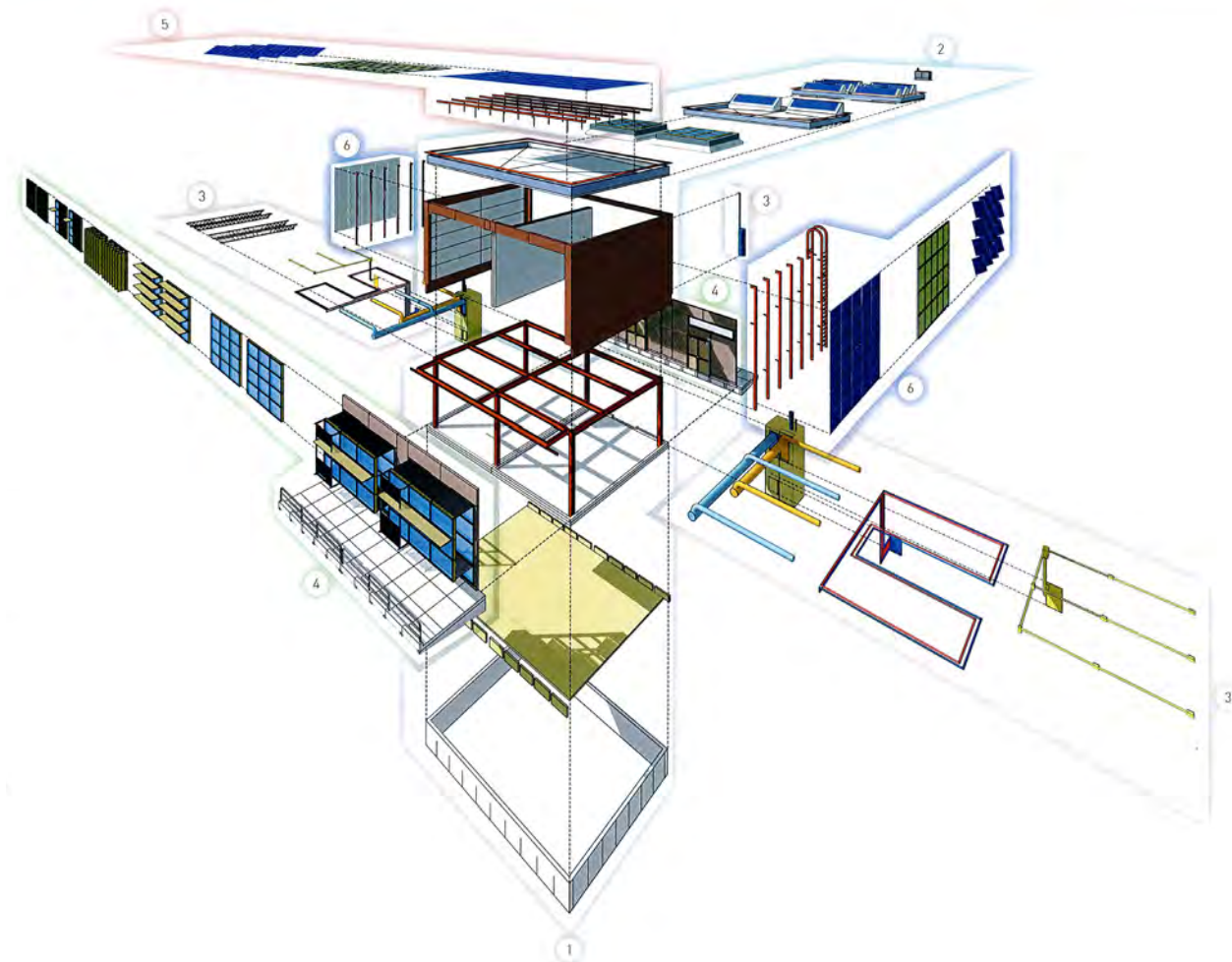


Diagram of testbed cell showing access and setup, test, and work zones.



Exploded view concept showing capability for replaceable and interchangeable systems.



# FLEX for Lighting – Use Case

Can industry reliably deliver high-performance lighting solutions at 1 kWh/(sf-yr)?

## The Challenge

Lighting is one of the largest loads in commercial buildings, and low-power density (W/sf) installation requirements are increasingly common. However, gains in energy-efficient lighting of the size required for deep retrofit savings and zero-net energy buildings will require a shift to **performance-based metrics and design goals**.

What do designers, engineers, and manufacturers need to develop advanced lighting control systems capable of **delivering low-energy lighting solutions, while maintaining indoor environmental comfort** and occupant satisfaction?

**FLEX** offers a unique opportunity for industry and researchers to collaboratively solve ‘stretch’ problems of this nature. **Consider the low-EUI lighting challenge**, and how **FLEX** provides a path to solution that cannot be found anywhere else in the world.

## Starting Point

A manufacturer has a **new lighting controls solution targeted for retrofit** applications that provides daylighting harvesting and occupancy control, setpoint tuning, and occupant personal control. The system has been bench-tested, component-tested, and function-tested in demonstration room environments. It has not undergone long-term performance testing with continuous high-resolution field-measured data.

## Solution Pathway

System **performance validation in FLEX’s 1980s vintage testbed**, with identical side-by-side test cells.

The manufacturer conducts a six-month field test, leveraging testbed measurement capabilities for energy performance and occupant comfort assessments that were not possible in the manufacturer’s company facilities.



Testing lighting controls.

| Testbed Capabilities  | Performance Parameters and Benefits  |
|---|--|
| Horizontal and vertical photometers   | Visual comfort – contrast, glare, ability to maintain worksurface illuminance  |
| Lighting system and fixture power   | System energy use, and peak demand; energy savings vs. 1980s base-case in twin cell; satisfaction of the 1kWh/(sf-yr) target |
| HVAC energy use   | HVAC impacts; whole-building or zone energy savings due to retrofit system   |
| Reconfigurable interior spaces  | Impact of changing reflectance, geometries, and sensor locations   |
| State of pre-existing shading devices (optional)                                      | Impact of shading on energy and visual comfort   |
| Exterior daylight conditions – cloud cover, irradiance, sun position                  | Impact of exterior conditions  |
| Robust data acquisition, accommodation of additional instrumentation                  | Flexibility to integrate experiment-specific measurement with existing testbed sensors                                       |
| Ability to interoperate and execute control across a variety of platforms and devices | Flexibility to test diverse systems and components, control solutions, and proprietary systems                               |

## Immediate Outcomes

- Validated **system energy savings relative to the 1kWh/sf-yr target**.
- Optimized sequences of operation, energy and comfort performance metrics, whole building energy savings and HVAC dependencies.
- Holistic archival set of **high-quality field-measured data** (dozens of points) for use in manufacturer documentation and publications.
- Comprehensive experimental results to adjust system control logic, or component performance, if energy or comfort targets are not met.

## Extended Validation & Deployment Opportunities

- Conduct a performance test in **FLEX's rotational testbed** to determine performance under diverse orientations.
- Introduce occupants through **human subjects testing** – shift experimental focus to occupant satisfaction and personal control.
- Use the virtual design testbed, and simulation tools such as Modelica and Radiance to develop robust calibrated models; **partner with LBNL researchers with subject matter expertise**.
  - Use field-measured data to **extend experimental findings – diverse climates, room geometries, envelope, and HVAC systems**.

- Identify **critical performance drivers** and associated measurement solutions **for operational diagnostics, continuous commissioning, and reporting**.
- Build partnerships with **early-adopter FLEX members** to conduct scaled demonstrations in real-world buildings across the nation.
- Use experimental data, in combination with access to **utility/state testbed members**, to expose benefits to new incentive programs and future code requirements.
- Provide anonymized system design and operational performance data to members of the **architecture & engineering community** using the virtual design testbed.
  - Industry-standard design and simulation tools support designers to gain confidence in specifying the low-energy retrofit lighting system.

---

## References and Further Reading

Granderson, J, Gaddam, V, DiBartolomeo, D, Li, X, Rubinstein, F, Das, S. Field-measured performance evaluation of a digital daylighting system. 2010. Leukos, Journal of the Illuminating Engineering Society of North America 7(2): 85-101.

Wen, Y-J, DiBartolomeo, D, Rubinstein, F. "Co-simulation Based Building Controls Implementation with Networked Sensors and Actuators," Proceedings of the 3rd ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Buildings (BuildSys'11), 2011.

---

# FLEX for HVAC – Use Case

Can industry increase the effectiveness of low-capacity, low-energy cooling systems for both retrofit and new construction applications?

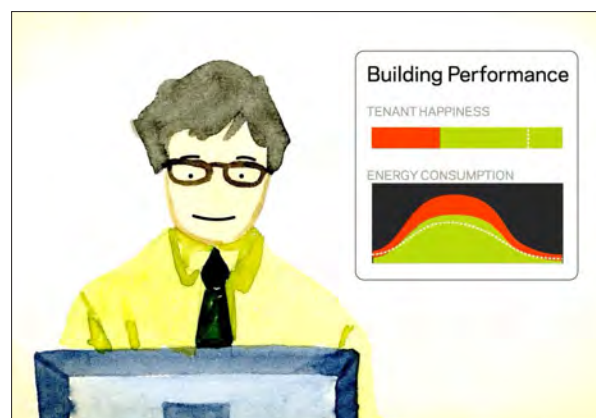
## The Challenge

Radiant cooling, chilled beams, displacement ventilation, and UFAD systems pose tremendous potential to lower cooling energy use and deliver thermal comfort. However, adoption of these technologies has largely been limited to new construction applications in which thermal loads can be lowered and controlled through building envelope and interior lighting designs. These systems' capacity and effectiveness in meeting thermal load and comfort requirements of perimeter spaces is a result of their interactions with the building façade and interior loads from lighting and other devices. Understanding how these elements affect system performance will illuminate opportunities to guide product, system, and controls design, and will improve product effectiveness at meeting load requirements for both retrofit and new construction applications.

For example, it has been understood that convection plays a large role in maximizing the cooling output of radiant panels or slabs. However, interactions and impact of convection that occur in typical buildings (e.g. convective effects from lighting systems and façades) are not well understood. With further insight into thermal performance impacts on radiant cooling, opportunities will emerge to **work synergistically with lighting and façade systems to increase cooling effectiveness** under various operating conditions.

What do designers, engineers, and manufacturers need to develop advanced cooling systems capable of **delivering low-energy cooling solutions, while maintaining indoor environmental comfort** and occupant satisfaction?

**FLEX** offers a unique opportunity for industry and researchers to collaboratively solve 'stretch' problems of this nature. Consider the challenge of radiant cooling panels and their interactions with convection from various façade types; FLEX provides a path to solutions that cannot be found anywhere else in the world.



Delivering thermal comfort and low energy use.

| Testbed Capabilities  | Performance Parameters and Benefits  |
|---|--|
| Horizontal and vertical interior surface temperature measurement                      | Air and radiant temperature distribution of the space, relates to thermal comfort                  |
| Room imaging and visualization  | Space thermal distributions  |
| Lighting system and fixture power   | System energy use, and peak demand; energy savings vs. 1980's base-case in twin cell               |
| Temperature and flow of HVAC utilities  | HVAC thermal loads   |
| HVAC energy use   | HVAC impacts; whole-building or zone energy savings due to retrofit system                         |
| Reconfigurable interior spaces  | Create multiple zonal conditions – perimeter and core applications                                 |
| Reconfigurable glazing  | Impact of glazing on convection, thermal loads, radiant cooling output, energy and thermal comfort |
| Reconfigurable shading  | Impact of shading on convection, thermal loads, radiant cooling output, energy and thermal comfort |
| Robust data acquisition, accommodation of additional instrumentation                  | Flexibility to integrate experiment-specific measurement with existing testbed sensors             |
| Ability to interoperate and execute control across a variety of platforms and devices | Flexibility to test diverse systems and components, control solutions, and proprietary systems     |

## Starting Point

A manufacturer has a **radiant cooling product** and is interested in evolving its application in the retrofit and new construction markets. The radiant cooling product has been bench-tested, component-tested, and demonstrated in a room environment, isolated from interactions with the wider array of building interior systems and convective sources. It has not yet undergone extensive long-term performance testing for interactions with, and impacts of, convection from various grades of glazing and shading systems, with continuous high-resolution field-measured data.

## Solution Pathway

System **performance validation in FLEX's 1980's vintage testbed**, with identical side-by-side test cells.

The manufacturer conducts a field test, leveraging testbed measurement capabilities for energy performance and occupant comfort assessments that were not possible in the manufacturer's in-house facilities.

## Immediate Outcomes

- Cooling and convective capacity effects of façades and lighting systems.
- Energy, thermal load and comfort performance metrics.
- Validation of sequences of operations, **system energy savings relative to a base case cell**.
- Holistic archival set of **high-quality field measured data** (dozens of points) for use in manufacturer documentation and publications.
- Comprehensive experimental results and information to adjust system control logic, or component performance, if energy or comfort targets are not met.

## Extended Validation & Deployment Opportunities

- Conduct performance tests in **FLEX's rotating testbed** to determine performance under diverse orientations.
- Introduce occupants through **human subjects testing** in the 1980s, 2010, 2013 or net zero testbeds – shift experimental focus to occupant satisfaction and personal control.
- Use the virtual design testbed and simulation tools, like Modelica and Radiance, to develop robust calibrated models; **partner with LBNL researchers with subject matter expertise**.
  - Use field-measured data to extend experimental findings to diverse climates, room **geometries, envelope, and HVAC systems**.
- Work with LBNL researchers to **validate radiant cooling simulation algorithms** for use in annual energy simulation platforms such as EnergyPlus.
- Identify **low-energy controls and operations** strategies.
- Build partnerships with **early-adopter testbed members** to conduct scaled demonstrations in real-world buildings across the nation.
- Use experimental data, in combination with access to **utility/state testbed members** to expose benefits to emerging technology and new incentive programs, and for future code requirements.
- Provide anonymized system design and operational performance data to **members of the AE community** using the virtual design testbed.

## References and Further Reading

Bourassa, N, Haves, P, Huang, J. A Computer Simulation Appraisal of Nonresidential Low Energy Cooling Systems in California, LBNL-50677.

# FLEX for Demand Response – Use Case

## Linking Energy-Efficient Operations with Automated Demand Response

### The Challenge

The vast majority of new, low-energy building systems have clear concepts for energy efficiency. For example, dimming lighting, radiant cooling, demand-controlled ventilation all have clear objectives for low-energy operations. Less well known are the requirements for designing, operating and automating low-energy systems for demand responsiveness.

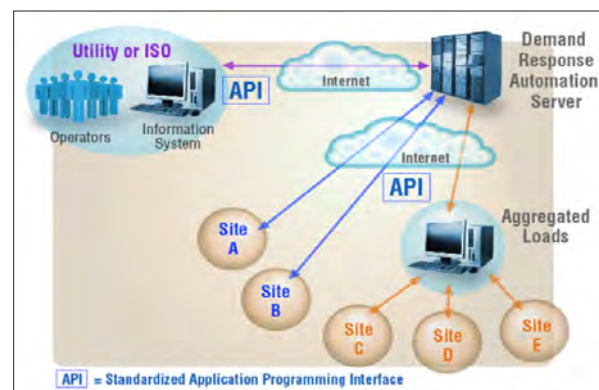
Consider **Demand Response (DR) control strategies** and how **FLEX** provides a path to solutions that will help accelerate innovation. **FLEX** offers high-quality continuous measurements combined with calibrated models of the facility to develop control strategies to evaluate how various sequences of operations perform at both the component and system level.

### Starting Point

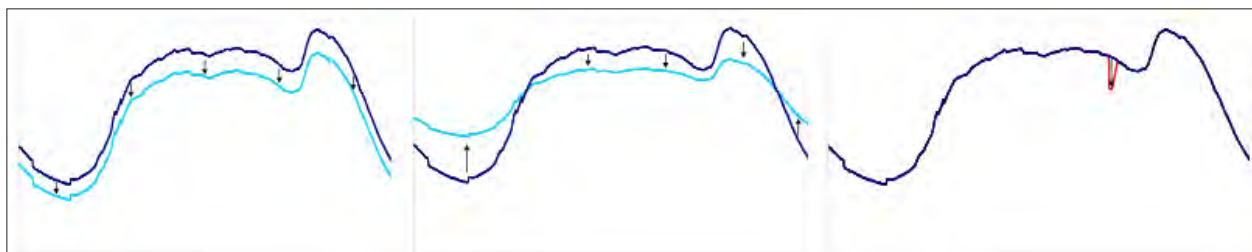
A control company or designer of a new “system” targeted for retrofit applications, that includes Automated Demand Response, lighting control, and advanced HVAC concepts. The system has been designed based on the capabilities of the components, but has not been tested as an integrated system.

### Solution Pathway

The control company conducts a six-month field-performance test, leveraging testbed measurement and monitoring capabilities for energy performance and control strategy analysis to evaluate how the integrated system should operate in different modes – full service and full occupancy, reduced service, night time standby, and low-power.



**An Open Automated Demand Response (OpenADR) communications test facility, part of FLEX, incorporates a client-server automation architecture using an open application-programming interface.**



**Load shape modifications – energy efficiency, peak demand reduction, reliability response.**

| Testbed Capabilities   | Performance Parameters and Benefits   |
|--|---|
| Lighting system and fixture power and energy and demand                  | System energy use, and peak demand; energy savings relative to non-controlled 1980s retrofit base-case in twin cell |
| HVAC control and energy use  | Zonal load measurement, hydronic or air   |
| Robust data acquisition system to accommodate additional instrumentation | Flexibility to integrate experiment-specific measurement hardware with existing testbed instrumentation             |
| DR automation server and client designs                                  | Client-server capabilities, price and reliability signals, latency testing  |
| Energy and demand response models  | EnergyPlus and Modelica tools to model control strategies, HVAC, lighting, and whole “testbed” energy use           |



## Immediate Outcomes

- Validation or optimization of sequences of operations.
- Demand Response capabilities analysis.
- Immediate results and information to adjust system control logic, or component performance, if energy or comfort performance is lower than target.
- Extrapolate results for diverse climates and related designs.
- Use holistic archival set of high-quality field-measured data for documentation and publication.

## Extended Validation & Deployment Opportunities

- Explore a large variety of economic targets based on electricity tariff designs.
- Evaluate latency of control communications.
- Test interoperability with multiple control and automation and metering systems.
- **Partner with LBNL researchers** with subject matter expertise.

- Use field-measured data to inform critical performance drivers, and how to cost-effectively measure them, for as-installed operational diagnostics, continuous commissioning, and automated energy performance reporting.
- Build partnerships with **early-adopter FLEX members** to conduct scaled demonstrations in real-world buildings across the country.
- Use testbed and early adopter data, in combination with access to **utility/state testbed members**, to share benefits for emerging technology and new incentive programs, and to inform future code requirements.
- Provide generalized system design and operational performance data to **members of the engineering community** using the virtual design capabilities.

## References and Further Reading

Motegi, NA, Piette, MA, Watson, DS, Kiliccote, S, Xu, P. Introduction to Commercial Building Control Strategies and Techniques for Demand Response. Report for the California Energy Commission, PIER. LBNL-59975. May 2007.

Piette, MA, Ghatikar, G, Kiliccote, S, Koch, E, Hennage, D, Palensky, P, McParland, C. 2009. Open Automated Demand Response Communications Specification. California Energy Commission. CEC 500 2009 063.

Xu, P, Haves, P, Braun, J, Zagreus, L, Piette, MA. Demand Shifting With Thermal Mass in Large Commercial Buildings (Audit, Field tests and Simulation), December 2005. LBNL-58815.

# FLEX for Building Façades – Use Case

Can We create optimized façades that provide comfort, daylight and net zero energy performance?

## The Challenge

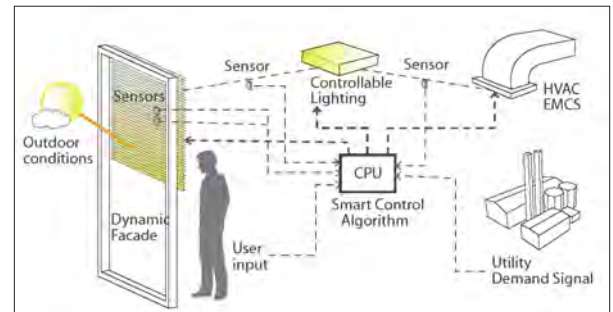
Optimizing the transparent elements in the building envelope to provide view and daylight, but minimizes winter heat loss, summer solar gain and glare, is a complex challenge. More stringent codes are limiting, but owners want large view windows. Dynamic solutions – smart glass, motorized shades and blinds, daylight redirecting systems – might help, but **there is enormous uncertainty in the actual performance of these dynamic systems.**

**No one wants unproven solutions, but accurate field data are impossible to find.** What do owners, designers, engineers, and manufacturers need to create smart and responsive façade and daylighting systems capable of **delivering net-zero energy performance, while minimizing peak cooling, maintaining view and providing visual and thermal comfort?**

FLEX offers a unique opportunity for industry and researchers to collaboratively solve a wide range of performance integration and optimization problems. It allows **exploration of façade performance while varying and controlling every key design and operating parameter:** room parameters, façade features, occupied vs unoccupied, and HVAC/lighting interaction. Tests can be done in one-story spaces, two-story spaces or a rotating testbed that can be fixed in different orientations or moved to follow the sun.

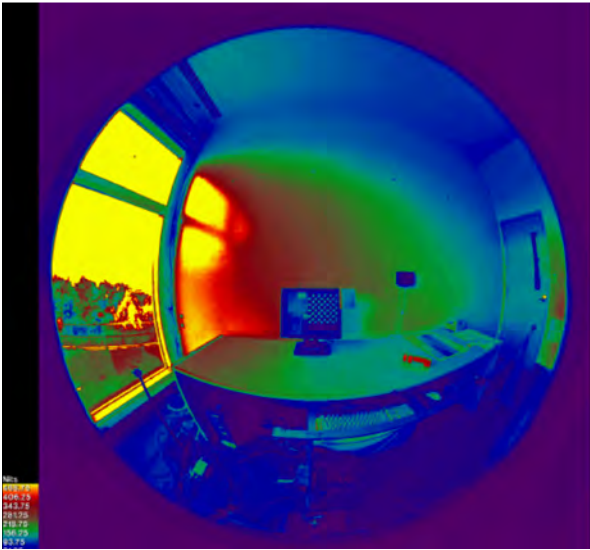
## Starting Point

Imagine an innovative design team with a demanding client who wants a near net-zero building, with a radiant floor cooling system with limited peak perimeter cooling capacity. **The client demands a highly glazed façade to meet competitive market needs, and requires that comfort conditions be maintained in immediate proximity to the glazing to maximize rentable interior space.** A possible kit of parts includes: high performance glazing/framing, daylight redirecting technologies, dynamic glazing/shading, all coupled to smart lighting controls and responsive HVAC controls. But **numerous challenges arise that simulation tools alone cannot fully solve:** for example: can the radiant system handle peak cooling? How to optimize daylighting and glare tradeoffs by season and room location? How will occupants react to integrated controls?



Systems integration issues measured in FLEX.

| Testbed Capabilities  | Performance Parameters and Benefits  |
|---|--|
| Complete photometric capture throughout the room with dynamic HDR capability          | Visual comfort – contrast, glare, ability to maintain worksurface illuminance  |
| Exterior daylight conditions—cloud cover, irradiance, sun position                    | Impact of exterior conditions  |
| Lighting system and fixture power   | System energy use, and peak demand; resolved fixture by fixture, time dependent correlated to daylight                     |
| HVAC energy use   | Peak cooling measurements; HVAC energy impacts   |
| Reconfigurable interior spaces  | Impact of changing workstations for user location and orientation vs. windows  |
| Optimization of shading devices and operation   | Compare systems across cells; optimized control of shading systems on energy (cooling/lighting) and thermal/visual comfort |
| Robust data acquisition, accommodation of additional instrumentation                  | Flexibility to integrate experiment-specific measurement with existing testbed sensors                                     |
| Ability to interoperate and execute control across a variety of platforms and devices | Flexibility to test diverse systems and components, control solutions, and proprietary systems                             |



Time lapse of interior room luminance with dynamic shading.

## Solution Pathway

To rapidly assess options, the design team, in coordination with the owner and key suppliers, conducts a series of tests in two testbeds, each with two experimental rooms, over a nine-month period that captures peak summer and winter test conditions. With four different design conditions, **the team focuses on two solutions that optimize cooling and make daylight secondary, and two other solutions that optimize daylighting.** One pathway explores fully dynamic shading solutions with electrochromic glazing and motorized exterior blinds, while the others provide low-SHGC glazing with manual blinds, with an active daylight control solution in the clerestory to daylight the full depth of the space. One of the testbeds is the rotating facility – which allows low-sun west-facing façades to be compared to south facades. Current performance vs. goals are tracked in real time using the LBNL-provided dashboards. **Once the design solutions have converged towards performance goals, a series of short-term experiments are made with staff occupying the spaces to assess comfort and acceptance.**

## Immediate Outcomes

- **Verification of basis of design** and that 70% energy savings goal can be accomplished.

- Comparative performance data on key design options allowing different design decisions to be made for glazing, shading, lighting, and HVAC.
- **Incorporate sequence of operations specified for control of shading, lighting and HVAC** into design specs.
- Insights into product improvements for **next-generation product development.**
- **Validation of simulation tools** over large performance range.
- **Occupant feedback** on system components and operational issues.
- Guidance for interior designers; **operating manual for occupants** based on test results.

## Extended Validation & Deployment Opportunities

- **Extend results to other orientations and other climates** using the virtual controls testbed and EnergyPlus tools.
- Advise ASHRAE 189, 90.1, LEED and **other mandatory and voluntary rating and code** bodies on issues of dynamic vs. static equipment and impact on achieving goals.
- Update **NFRC ratings and labeling programs** for commercial façades and windows.
- Explore variability of occupant response to a wider range of dynamic solutions and space layouts.
- Explore **alternate HVAC solutions** and integration schemes.
- Explore private office vs. open landscape design implications.
- Build partnerships with **early-adopter testbed members** to conduct scaled demonstrations in real-world buildings across the nation.

## References and Further Reading

Lee, ES, Selkowitz, S, et al. High Performance Building Facade Solutions. PIER Final Project Report. 2009. LBNL-4583E. Available from: <http://lowenergyfaçades.lbl.gov/>

Konis, K, Lee, ES, Clear, RD. 2010. Visual Comfort Analysis of Innovative Interior and Exterior Shading Systems for Commercial Buildings using High Resolution Luminance Images. Leukos, Journal of the Illuminating Engineering Society of North America 7(3): 167-188. LBNL-4417E.

# FLEX for Model Based Controls – Use Case

## Development of innovative controls algorithm for complex façade systems

## The Challenge

Although there exist a large number of complex façade systems for reduction of solar heat gains in buildings, there is still a lack of innovative control algorithms capable of delivering high-quality, low-energy solutions.

to implement on actual control hardware. LBNL developed software is then used to link the control hardware to the computer model of the desired test cell. This real-time implementation of physical hardware may have communication delays and signal quantification errors that were not part of the simulation model. Once the

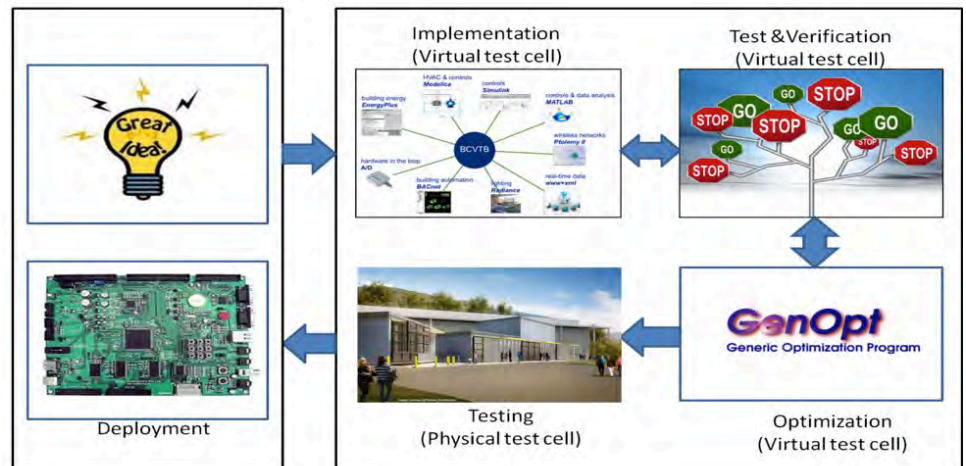
**FLEX** offers a unique opportunity for industry and researchers to collaboratively solve 'stretch' problems of this type by providing them a platform that can be used to develop, test and optimize innovative controls algorithms for complex façade systems.

## Starting Point

A controls company approaches LBNL with an idea to evaluate and optimize an innovative control algorithm for active façades before commercialization and deployment.

### Solution Pathway

The controls engineer verifies the correct operation of the control algorithm, offline, in a computer-model of a test cell. Since validated Modelica models for each test cell are available, one only needs to implement the controls algorithm for performance verification. The model is then used to further improve the algorithm, running annual simulations in a minute's time, thus allowing for multiple design iterations. Once the algorithm performs satisfactorily in simulation, the controls engineer automatically generates C code from the Modelica model



**A computer-based virtual testbed is part of the available FLEX resources. This virtual testbed incorporates Modelica models as software for implementation, testing, verification and optimization of innovative controls algorithms for complex façade systems.**

test implementation is successful, a three-months field performance test is conducted, in which the algorithm controls the façade systems of the physical test cell. The experiment is analyzed in real-time and compared to simulated reference data to identify and correct possible experimentation. Using physical measurements, the model is recalibrated and used to assess economic and energy benefits across different climate zones. Finally, the algorithm is commercialized, and results from the measurements are used to illustrate and explain the performance of the algorithm to customers.

| Testbed Capabilities   | Performance Parameters and Benefits  |
|--|--|
| Buildings simulation models  | EnergyPlus/Modelica/Radiance tools to model control strategies, lighting/HVAC, and whole “testbed” energy use    |
| Hardware-in-the-loop simulation tools                                    | Virtual test-bed to link different simulation tools during run-time and link simulation tools with real hardware |
| HVAC control and energy use  | Zonal load measurement   |
| Robust data acquisition system to accommodate additional instrumentation | Flexibility to integrate experiment-specific measurement hardware with existing testbed instrumentation          |



## Immediate Outcomes

- Developed and optimized control algorithms for active façades that achieve energy savings in buildings.
- Holistic archival set of high-quality field-measured data for use in manufacturer documentation and publications.
- Test-bed results and information to adjust system control logic, or component performance, if energy or comfort performance is lower than target.

## Extended Validation & Deployment Opportunities

- Use of field-measured data and virtual testing to simulate and extrapolate findings to diverse climates, room geometries, envelope types, HVAC systems, and whole-building performance.
- Partner with LBNL researchers with subject matter expertise.
- Use the virtual testbed to conduct optimization in virtual environment prior to time-consuming full-scale testing.
- Use the virtual testbed for hardware-in-the-loop simulation for verification and real-time monitoring.

---

## References and Further Reading

Wetter, M, Zuo, W, Nouidui, TS. Modeling of Heat Transfer in Rooms in the Modelica “Buildings” Library. Proc. of the 12th IBPSA Conference, p. 1096-1103. Sydney, Australia, November 2011.

Nouidui, TS, Wetter, M, Li, Z, Pang, X, Bhattacharya, P, and Haves, P. BACnet and Analog/Digital Interfaces of the Building Controls Virtual Test Bed. Proc. of the 12th IBPSA Conference, p. 294-301. Sydney, Australia, November 2011.

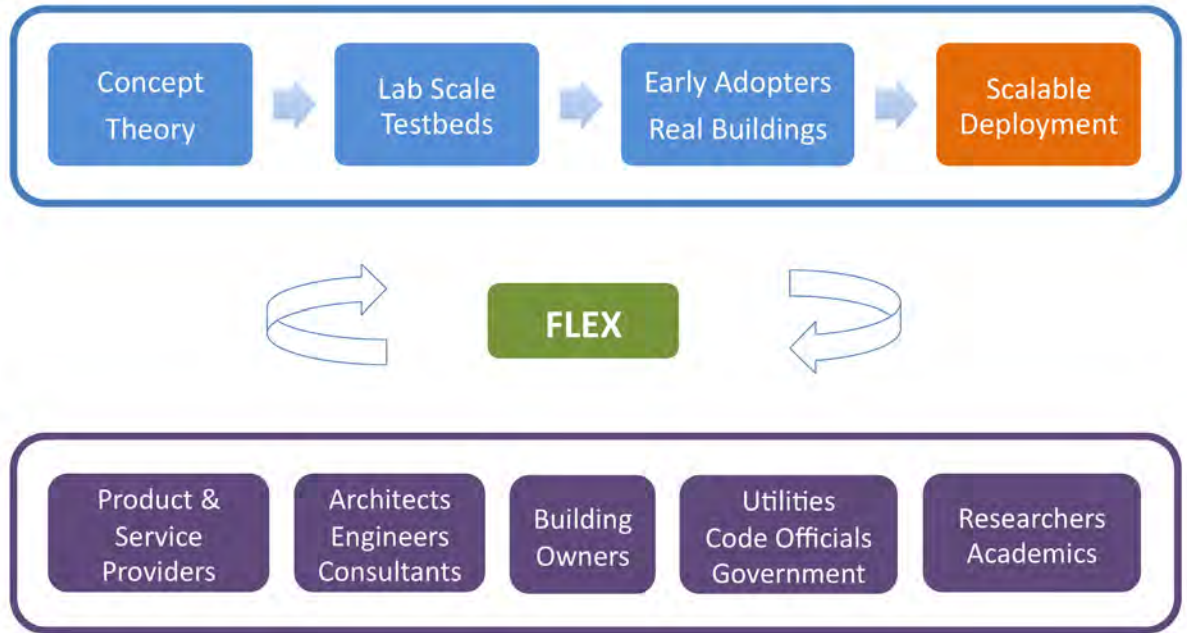
Wetter, M. Co-simulation of building energy and control systems with the Building Controls Virtual Test Bed. *Journal of Building Performance Simulation*, 4(3):185-203, 2011. Available from: <http://dx.doi.org/10.1080/19401493.2010.518631>

Wetter, M. Modelica-based Modeling and Simulation to Support Research and Development in Building Energy and Control Systems. *Journal of Building Performance Simulation*, 2(2):143-161, 2009. Available from: <http://dx.doi.org/10.1080/19401490902818259>

---

FLEX

Facility for Low Energy experiments in Buildings



# Get Involved

## The buildings industry will benefit from partnering with FLEX at the Berkeley Lab.

### Product & Service Providers

- More rapidly design, prototype and test new energy-efficient products and systems
- Receive feedback on system performance that will allow for design optimization
- Harvest performance data that drives increased investment in new technologies and systems
- Access to industry professionals for input on industry pain-points, deployment potential, and barriers to implementation
- Send visiting researcher for collaborative research with the Berkeley Lab
- Power to leverage investment with government and utility research grants
- Access to early adopters for emerging technology implementation

### Architects, Engineers, & Consultants

- Specify new innovative systems with confidence, thereby achieving higher energy performance targets
- Provide information on current deficiencies and needs in retrofit & new construction of energy-efficient buildings
- Participate in design and analysis of early adoption beta sites
- Provide expert advice on feasibility and barriers to innovative systems and technologies and jointly develop research goals
- Contribute to development of performance targets used for ‘technology challenge’ criteria (i.e. 1kw/sf lighting retrofit)
- Participate in quarterly meetings on research agenda, industry trends, and recent findings
- Train staff in cutting edge modeling & virtual design practices
- Gain insight and influence on regulatory and utility incentive trends

### Building Owners

- Reduce financial risk of portfolio-wide energy efficiency implementation
- Increased confidence in investing in high efficiency retrofit solutions and new buildings
- Provide information on current deficiencies and needs in retrofit & new construction of energy-efficient buildings
- Actively contribute development of performance targets used for ‘technology challenges’
- Implement successful products/strategies in pre-determined ‘early adoption’ square footage
- Contribute to R&D agenda, and development of performance metrics used to evaluate control strategies and emerging technologies

### Utilities, Code Officials, & Government

- Ability to more accurately predict EE program impacts
- Ability to tighten existing codes or offer new rebates and incentives based on confidence in measured performance data under realistic conditions

### Researchers & Academics

- Access to high-quality performance data to advance R&D in new technology
- Validation of simulation tools and methods
- Insights into opportunities of new breakthroughs



For more information on FLEX or opportunities to partner with the Berkeley Lab please contact us:



Oren Schetrit  
[oschetrit@lbl.gov](mailto:oschetrit@lbl.gov)  
510-486-5649  
[www.lbl.gov](http://www.lbl.gov)  
[utbf.lbl.gov](http://utbf.lbl.gov)